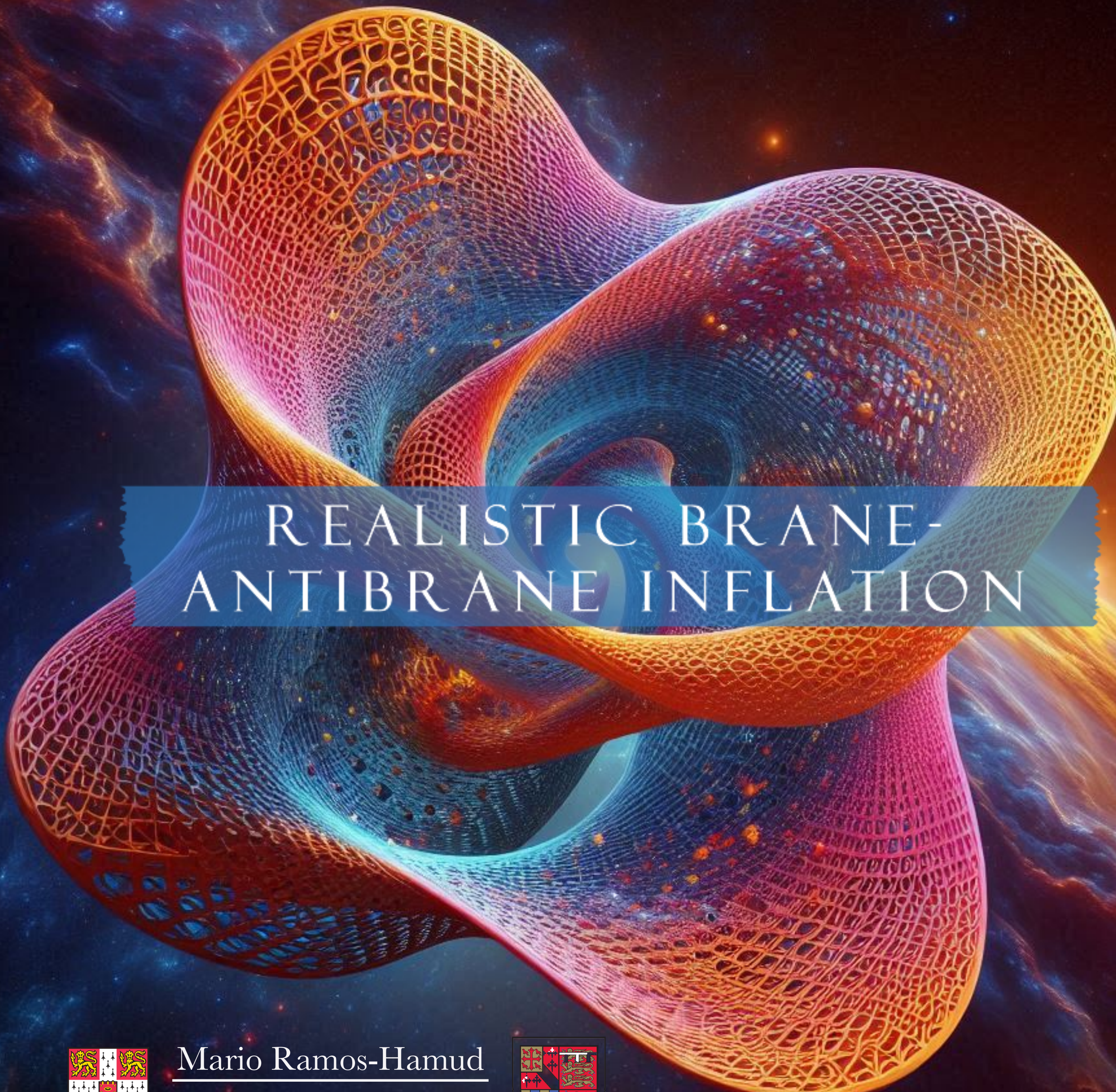
String Phenomenology Conference 2024

Centro Culturale Altinate - San Gaetano - Padova (Italy)



REALISTIC BRANE-ANTIBRANE INFLATION

Mario Ramos-Hamud

University of Cambridge

Thursday, 27th June 2024

CONACYT

CAMBRIDGE COMMONWEALTH EUROPEAN AND INTERNATIONAL TRUST

Collaboration

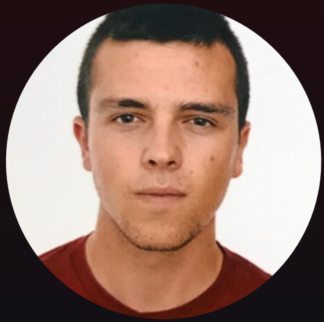
M. Cicoli

C. Hughes

A. Rakin

F. Marino

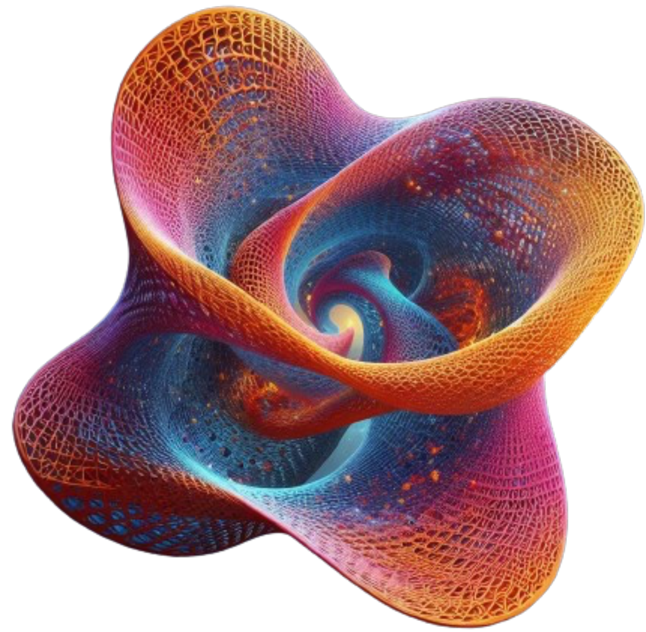
F. Quevedo



G. Villa

Outline

- Motivation
- Perturbative corrections
- Perturbative modulus stabilisation
- Brane anti-brane inflation
- Conclusions



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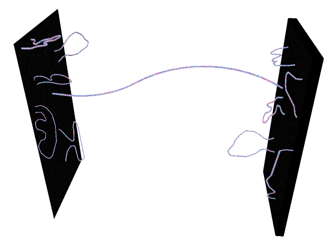

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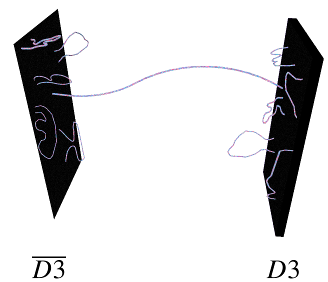

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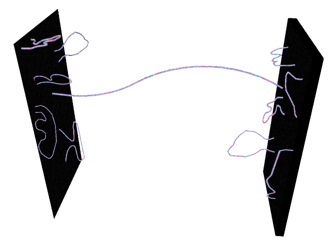

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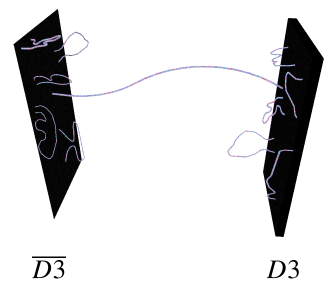

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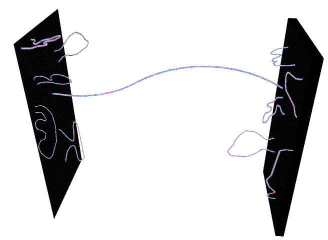

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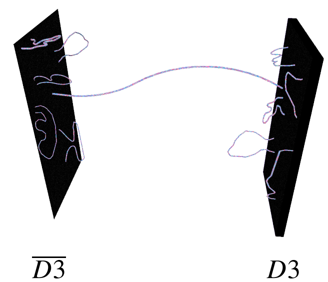

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$$K = -\ln(s) - 3\ln\left(\tau - \alpha\ln[\tau] + \frac{\xi s^2 - 3D\ln(\tau)}{3s^{1/2}\tau^{1/2}}\right),$$

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The leading order **scalar potential**:

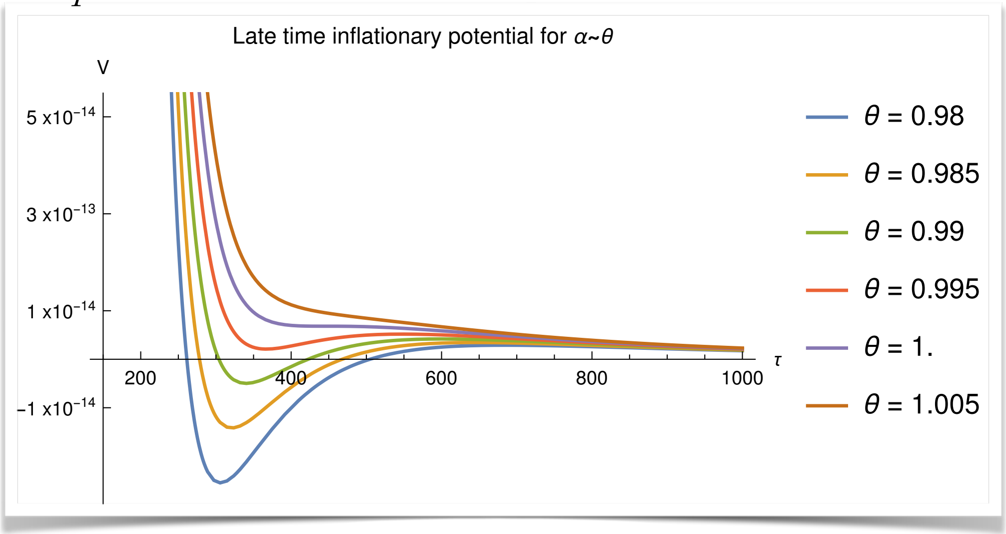
$$\frac{Vs}{3|W_0|^2} = \frac{\alpha}{\tau^4} + \frac{s^2\xi + \mathcal{O}(1/s^2) - 3D\ln\tau}{4s^{1/2}\tau^{9/2}} + \mathcal{O}\left(\frac{1}{\tau^5}\right),$$

Mininum: $\quad \tau_* = \exp\left(\dfrac{s^2\xi}{3D} + \dfrac{2}{9} - 2\mathcal{W}_0\left[\dfrac{\theta}{e}\right]\right)$ with $\theta := \dfrac{16}{27}D^{-1}s^{1/2}\alpha\; e^{\frac{s^2\xi}{6D}+\frac{10}{9}}$ and

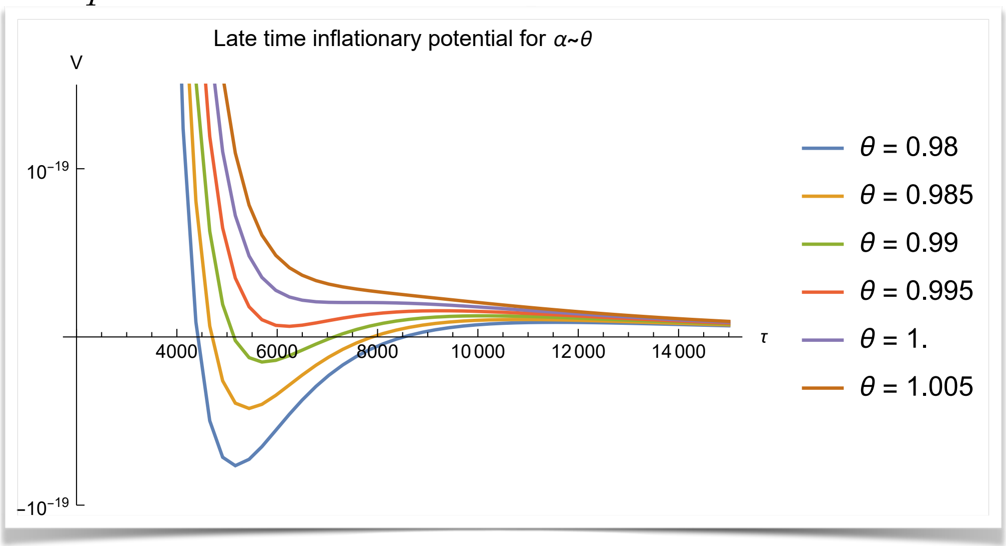
$$\alpha \sim \frac{D}{\sqrt{s\tau_*}}\,.$$

Perturbative stabilisation

Only-leading-term perturbative corrections:



Including all known perturbative corrections:



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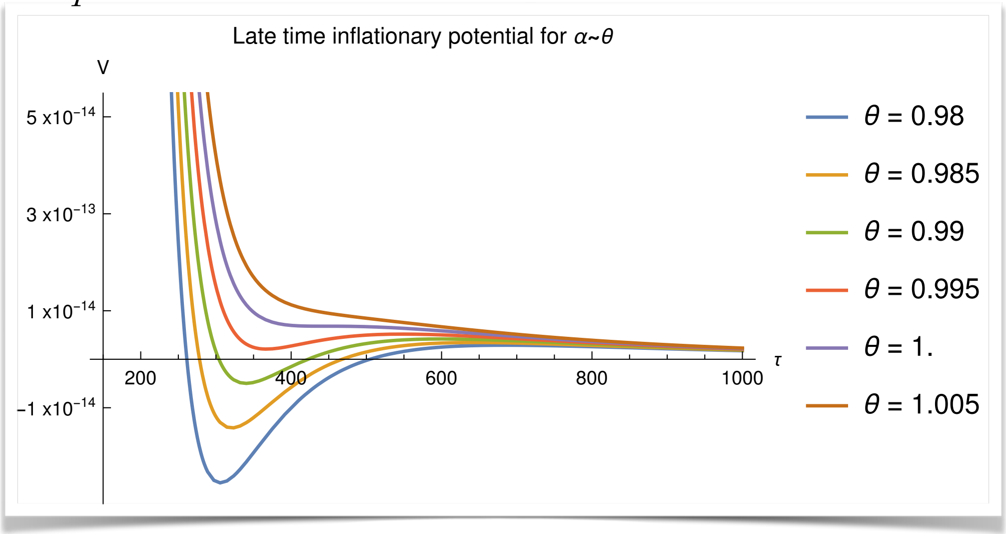

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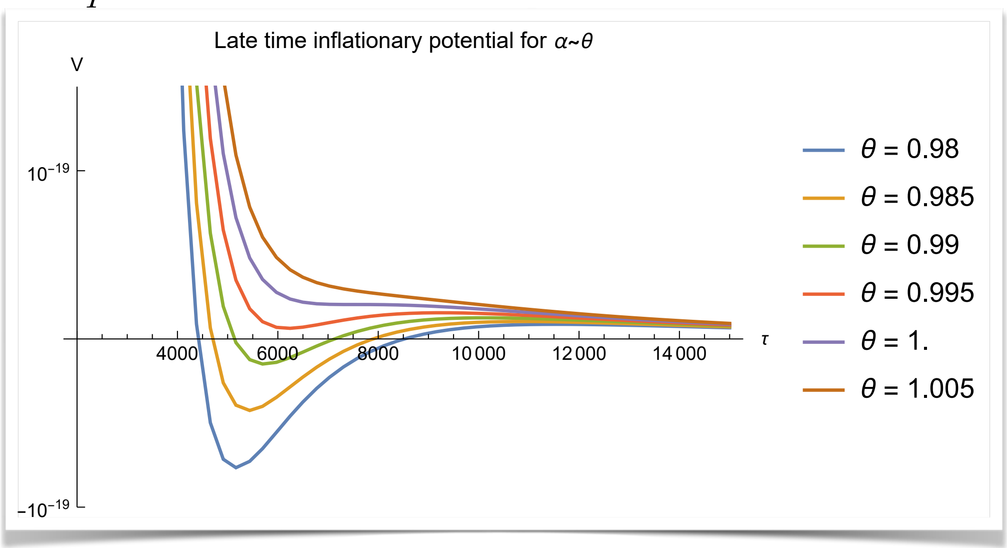

In both cases, increasing values of θ moves AdS → dS → runaway.

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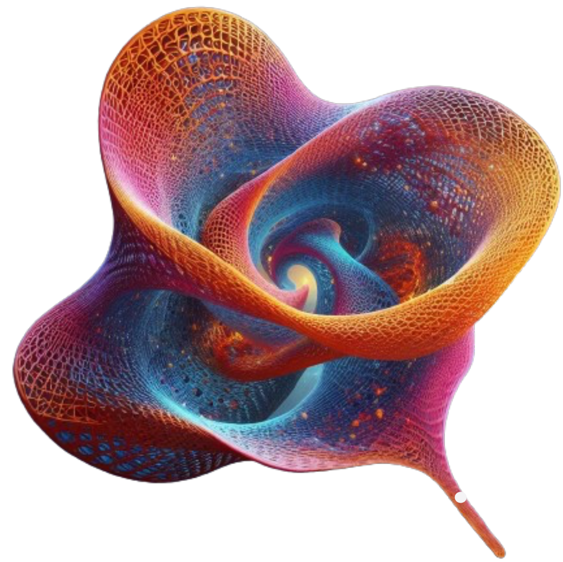

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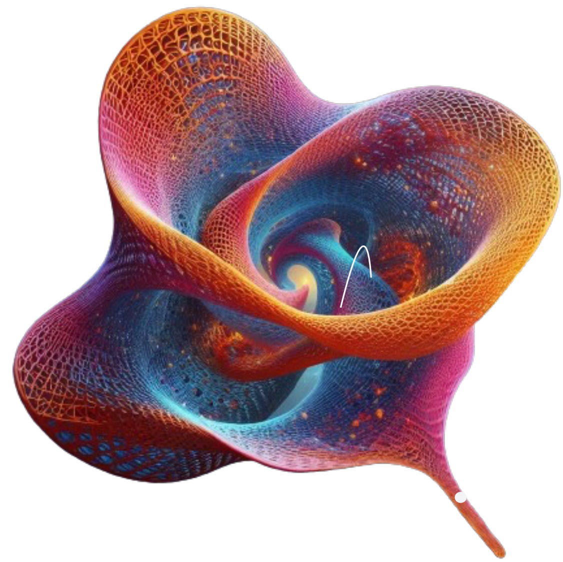

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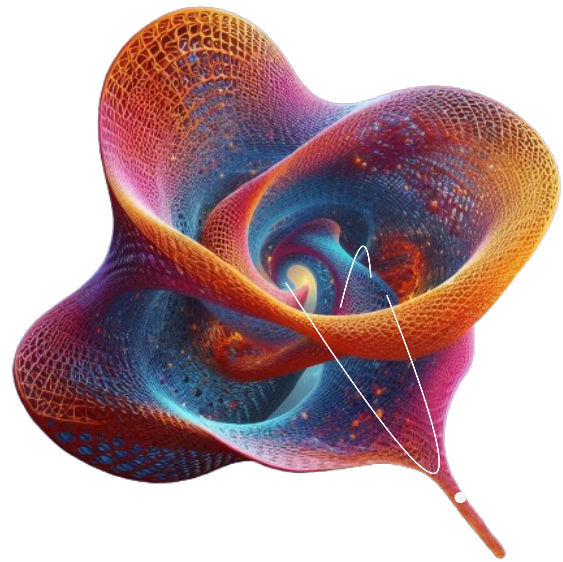

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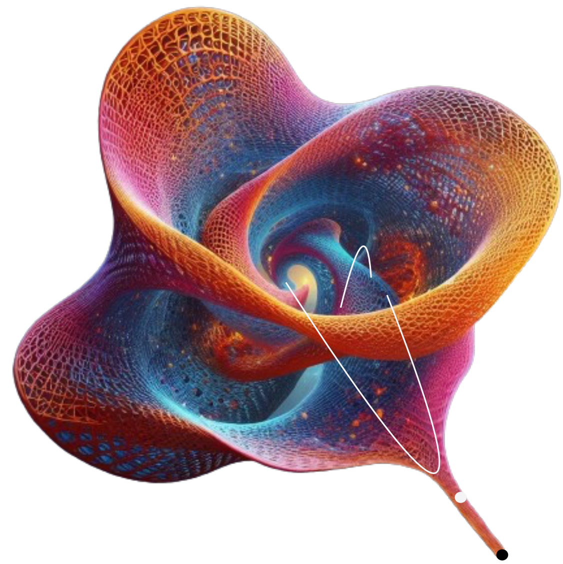

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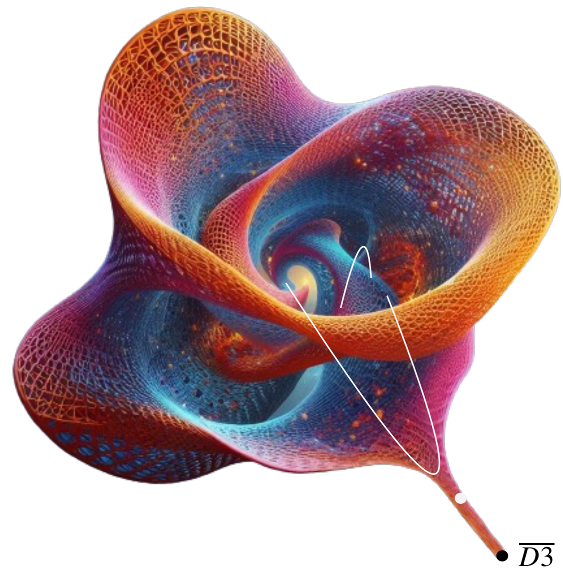

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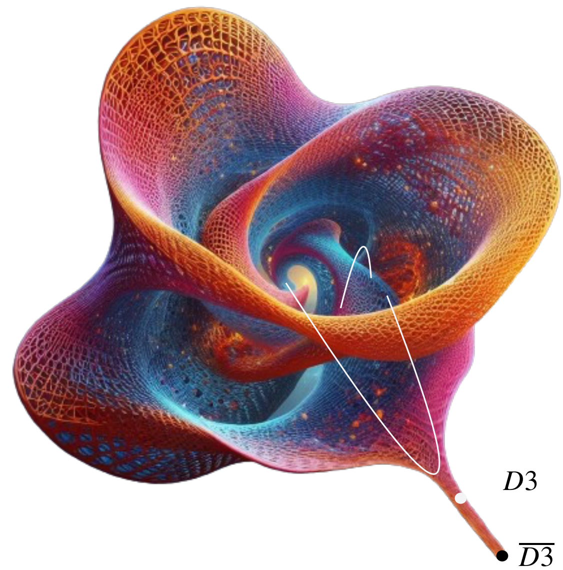

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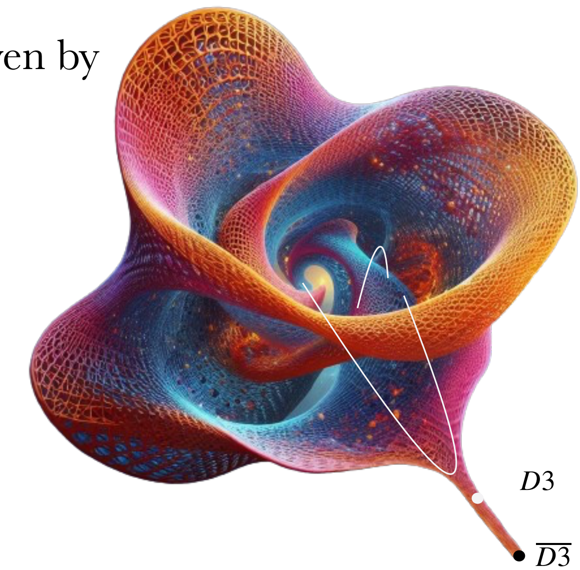

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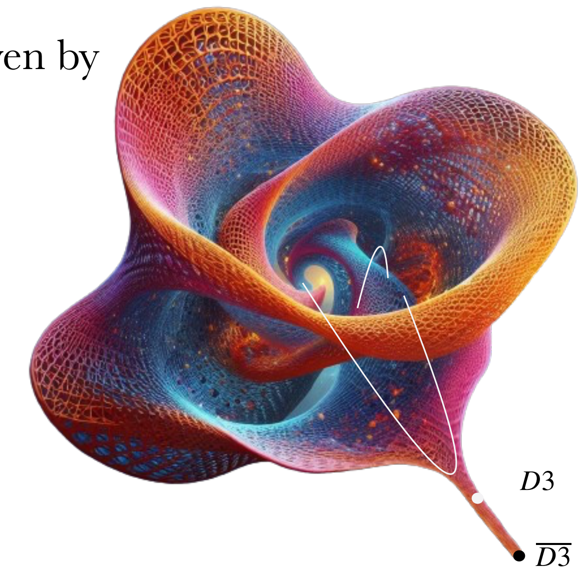

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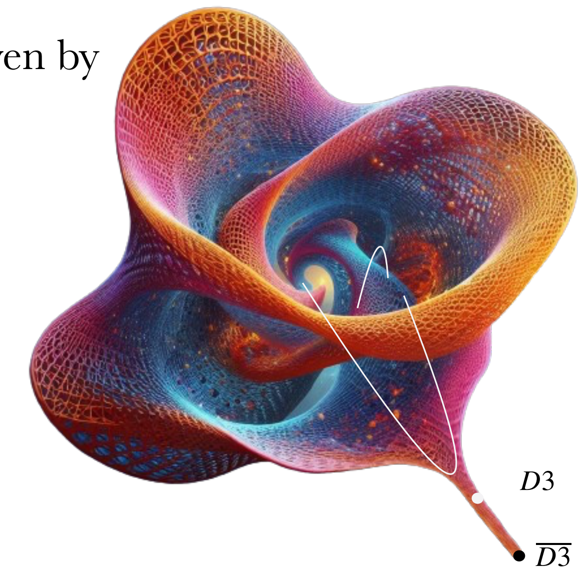

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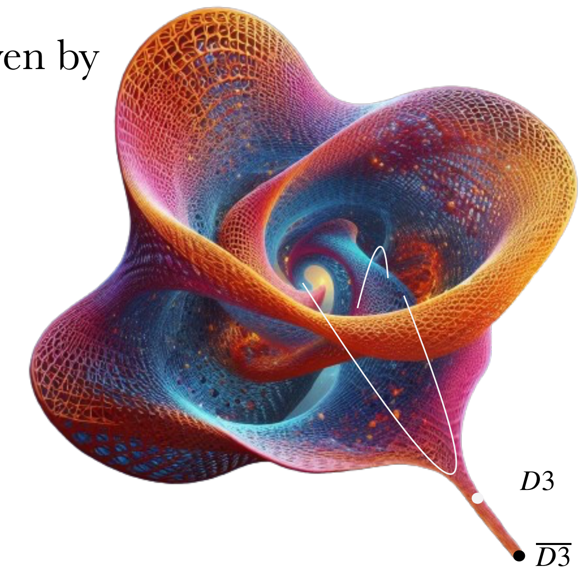

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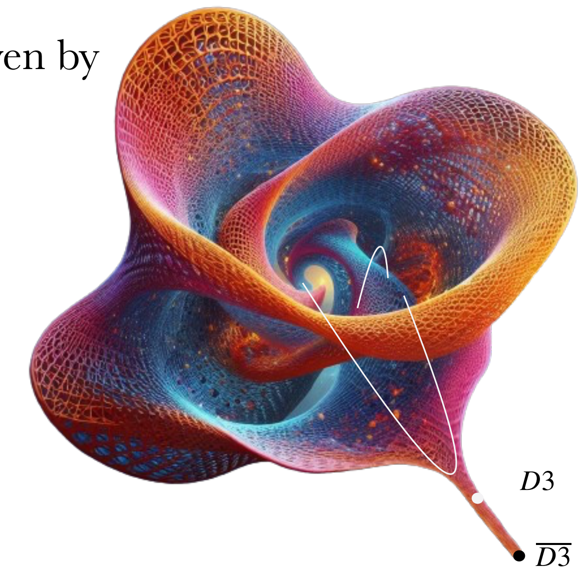

Nilpotent superfield framework:

The setup can be studied using non-linear SUSY with a **goldstino** superfield X breaking SUSY:

$$K = -3 \ln \left(f(\tau) + (X + \overline{X})\, g(\tau) + X\overline{X}\, h(\tau)\right),$$

and

$$W = W_0 + X W_X.$$

So we divided our study in two scenarios:

- Case with $g(\tau) \neq 0$.
- Case with $g(\tau) = 0$.

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meanwhile the scalar potential becomes

$$\frac{V}{W_0^2} = \mathscr{A}\frac{\delta^2}{\tau^2} + \mathscr{B}\frac{\delta}{\tau^3} + \mathscr{C}\frac{1}{\tau^4} \quad , \quad \delta = \frac{|W_X|}{|W_0|}.$$

LINEAR TERM INCLUDED

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2. We uplift to dS by considering the value of V_{NLO} at this minimum and restore α.

Linear term included

The Kähler potential with the computed corrections is

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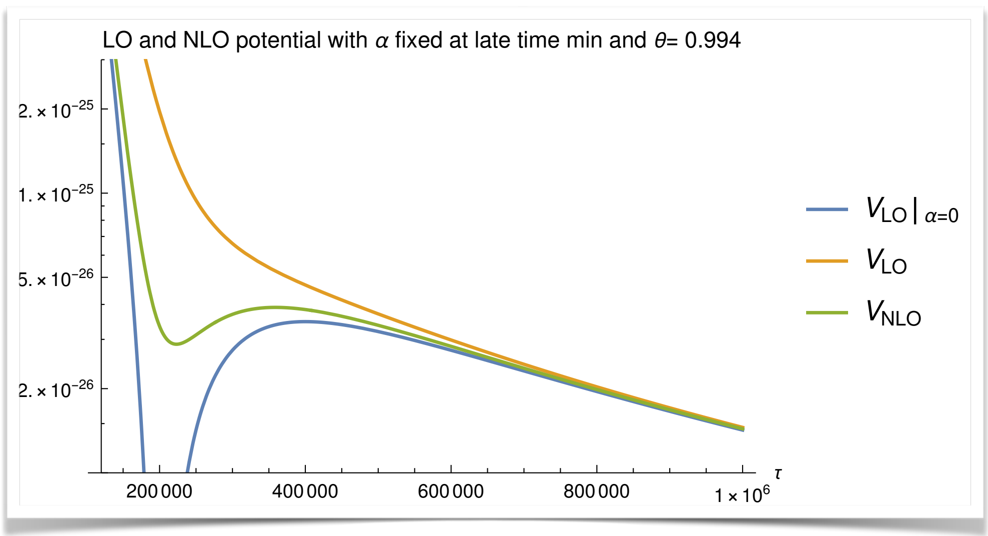

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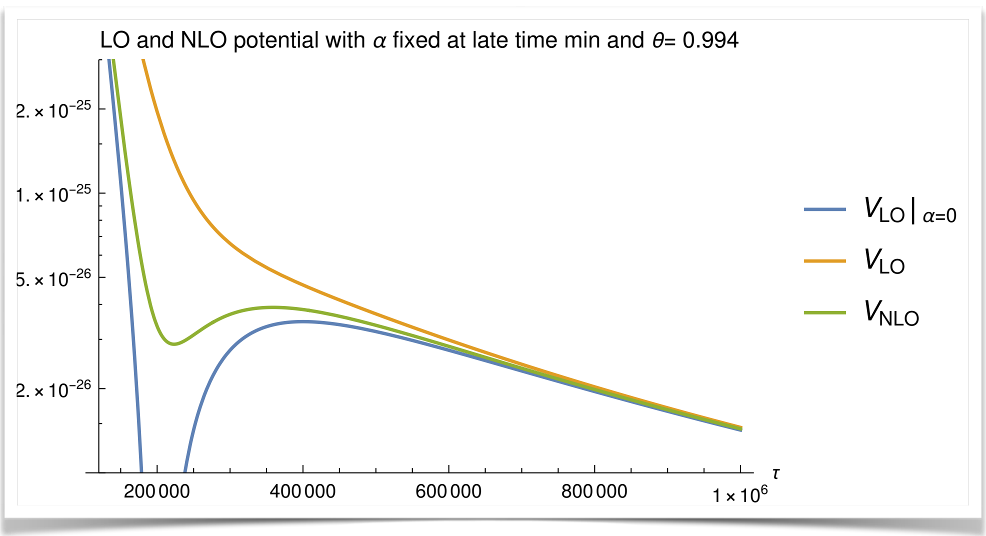

Figure.- Parameter space: $s = 15$, $a = 1$, $W_0 = 1$, $\delta = 10^{-6}$, $\xi = 0.1$, $A = 1$. NNLO terms are suppressed.

WITHOUT LINEAR TERM

Without linear term

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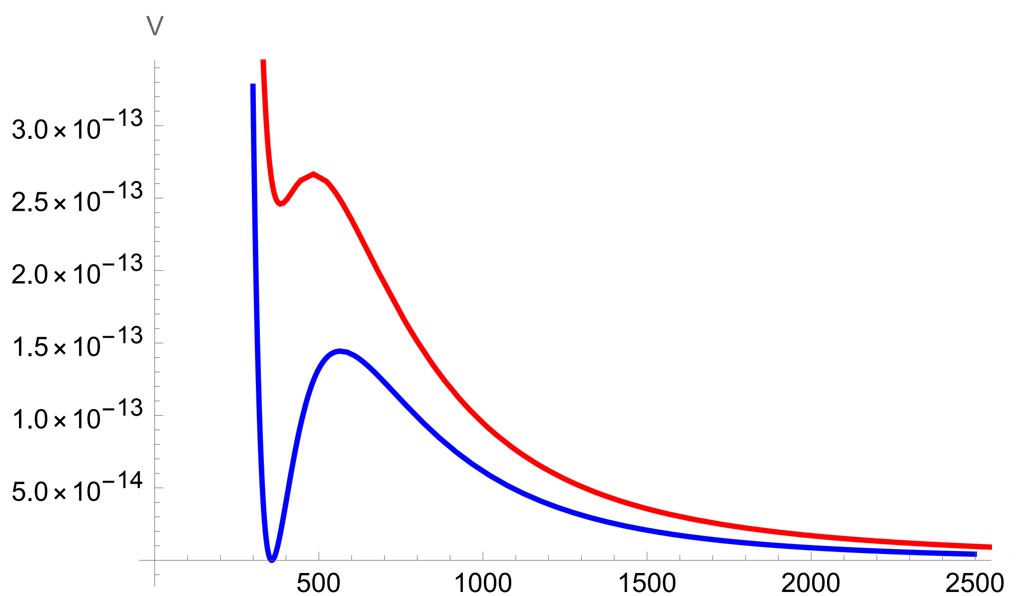

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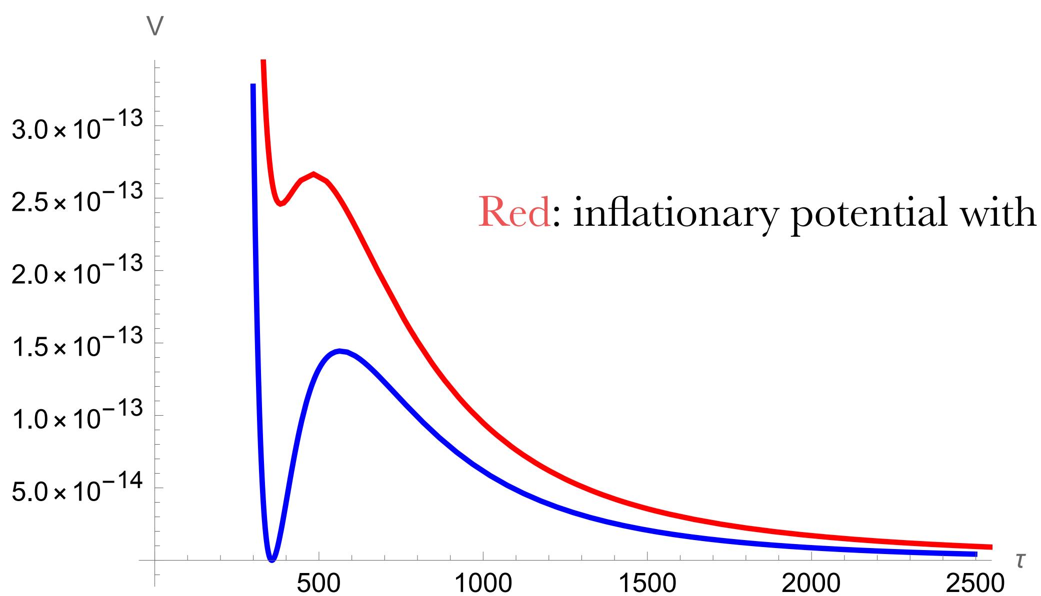

Red: inflationary potential with $\delta^2 \sim 10^{-7}$.

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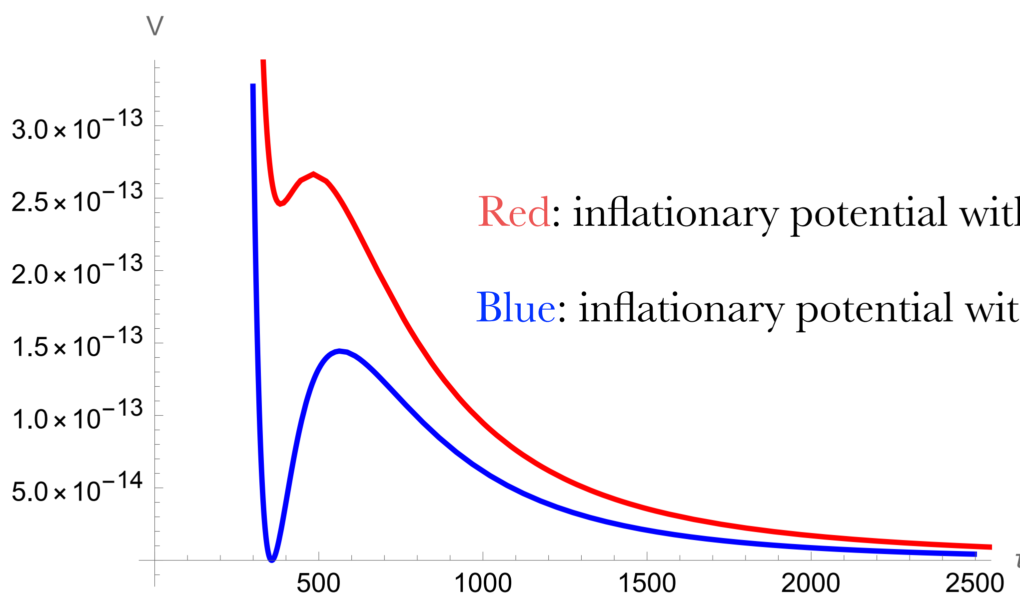

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Blue: inflationary potential with $\delta^2 = 0$.

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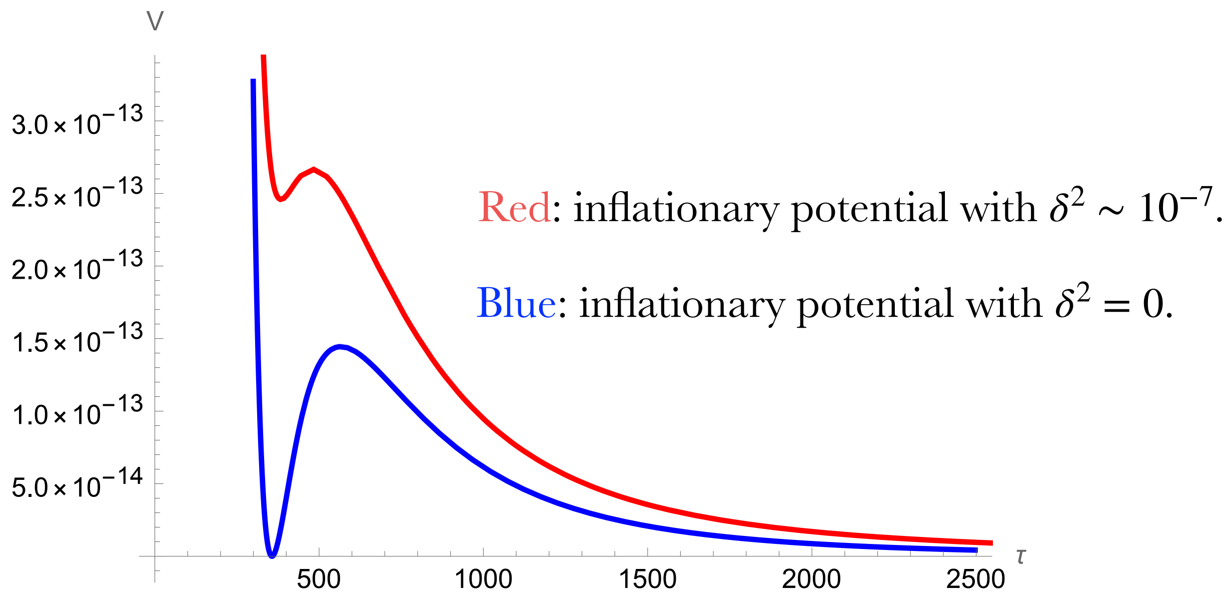
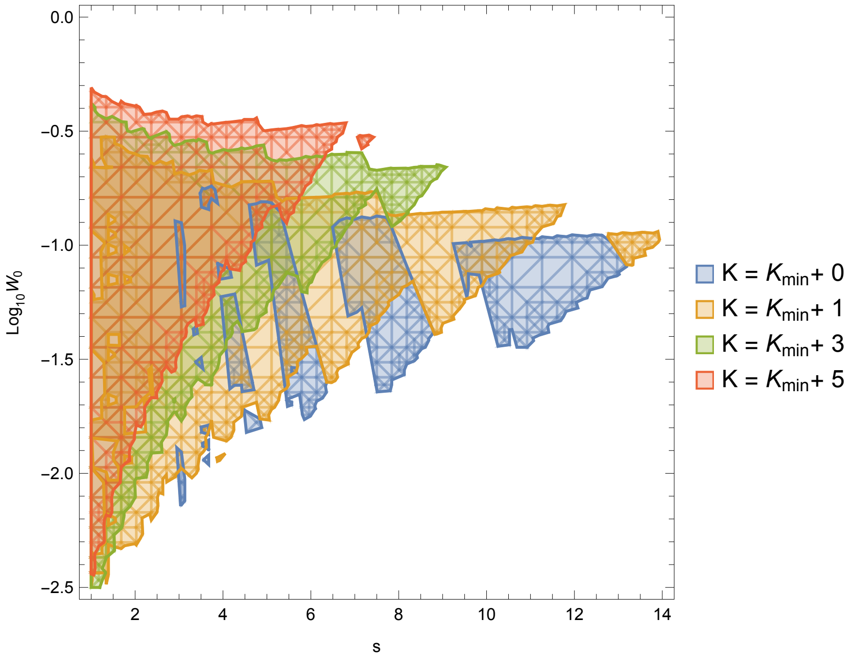


The minimum is at $V^{\text{inf}}_{\text{min}} \sim 10^{-13}$ and late minimum is approximately Minkowski.

Consistency constraints for inflation

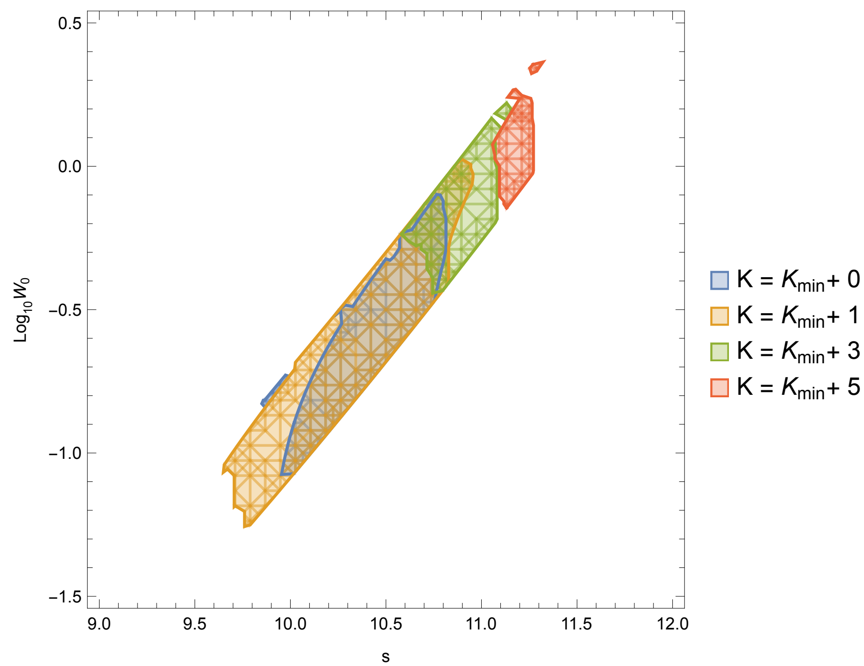
- Inter-brane separation larger than string length: $\varphi^4 > \dfrac{\mathfrak{b} M K g_s^3}{(2\pi)^4 \mathscr{V}^{4/3}} e^{-4\rho}$.
- Proper separation smaller than the KK length scale: $\varphi^4 < \dfrac{\mathfrak{b} M K g_s^3}{(2\pi)^4 \mathscr{V}^2}$.
- Gravitino mass condition: $W_0 \dfrac{\sqrt{g_s}}{\mathscr{V}^{1/3}} \ll 1$.
- Curvature corrections at the tip of the throat: $g_s M \geq 1$.
- Conifold modulus stability: $g_s M^2 \geq 46$.
- Non-singular bulk condition: $\dfrac{\mathscr{V}^{2/3}}{KM} \gg 1$.

Results



Parameter space **with** linear contribution

Parameter space **without** linear contribution



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For extra details and further questions please visit the homonymous poster session by Ahmed.

"The invisible and the non-existent look very much alike."

-S. Weinberg.

GRATZIE !

Mario Ramos Hamud
Email: mr895@cam.ac.uk
DAMTP | University of Cambridge

String Phenomenology Conference 2024

BACKUP SLIDES

η-PROBLEM

η-PROBLEM

Consider the Kähler potential

$$K \simeq -3\ln[\tau - \phi\bar{\phi} + \cdots].$$

when τ is fixed by **non-perturbative effects**, $\phi\bar{\phi}$ induces a correction to the inflaton potential given by

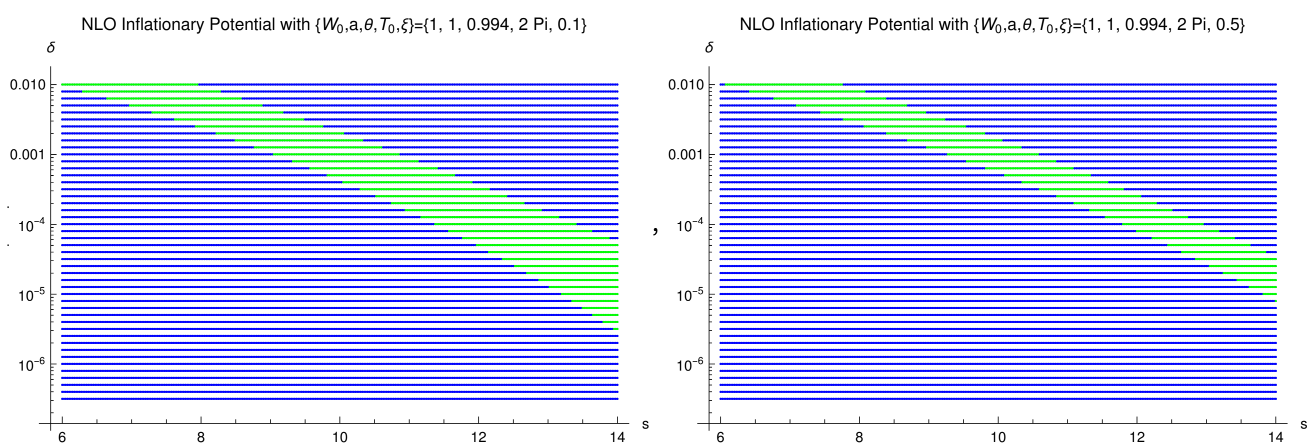
$$V_{\text{correction}} \sim \frac{V_{\text{original}}}{\tau^3}\phi\bar{\phi},$$

with V_{original} fixing the Hubble scale during inflation: $H_I^2 \sim \frac{V_{\text{original}}}{\tau^3}$.

- The mass contribution of the inflaton is $m_\phi^2 \sim \frac{V_{\text{original}}}{\tau^3} \sim H_I^2$
- Slow roll parameter: $\eta \sim \frac{V''}{V} \sim \frac{m_\phi^2}{H_I^2} \sim 1 \;\Rightarrow$ No longer slow-roll inflation!

η-problem can be avoided by doing a **perturbative stabilisation of the volume modulus.**

Linear term part I



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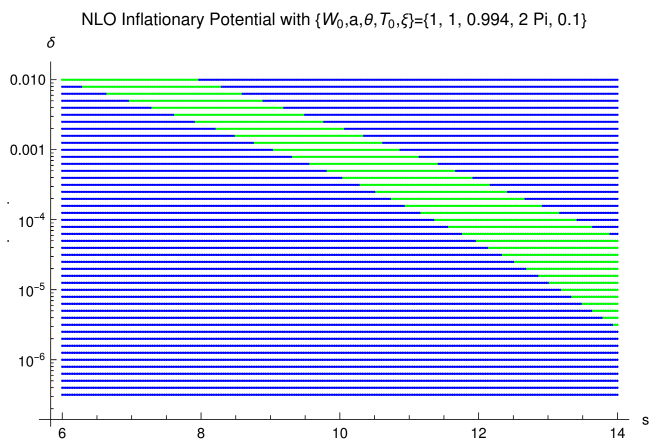
where

- $\mathscr{A} = \dfrac{1}{3s} + \dfrac{a^2\left(1 - 2\ln(\tau) + 3\ln(\tau)^2\right) + 2\alpha s^2\ln(\tau) - 2As}{3s^3\tau} + \ldots,$

- $\mathscr{B} = -\dfrac{2a}{s^2} - \dfrac{2a\left[a^2\left(1 - 2\ln(\tau) + 3\ln(\tau)^2\right) - s\ln(\tau)(3A - \alpha s) - 2s(A - \alpha s)\right]}{s^4\tau} + \ldots,$

- $\mathscr{C} = \dfrac{3\left(a^2 + \alpha s^2\right)}{s^3} + \dfrac{3\left(\xi s^2 + 8D + 3\sigma - 3D\ln(\tau)\right)}{4s^{3/2}\tau^{1/2}} +$
  $+ \dfrac{3\left(3a^4\ln^2(\tau) + a^4 - 2a^2s(A - 2\alpha s) - 2\ln(\tau)\left(a^4 + 3a^2As - \alpha^2s^4\right) + s^2\left(3A^2 - 2\alpha As + 3\alpha^2s^2\right)\right)}{s^5\tau}$



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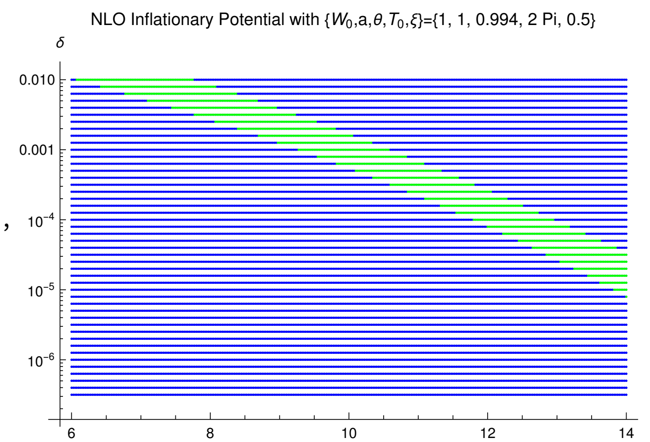

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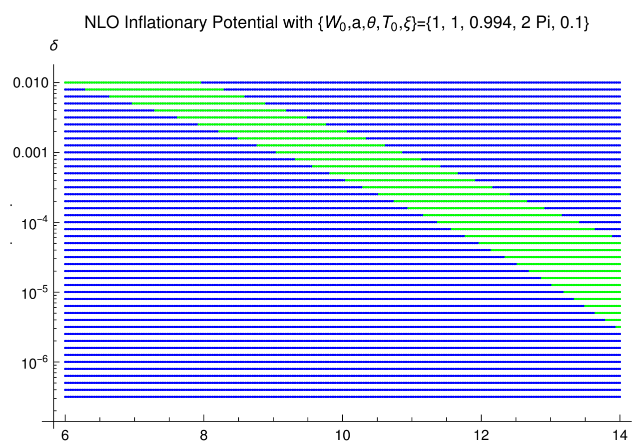

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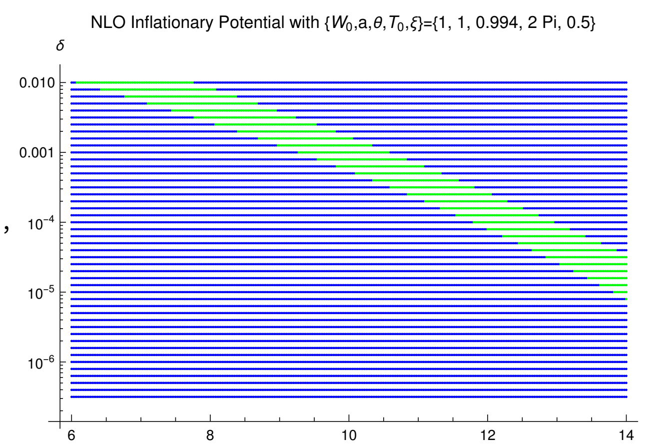
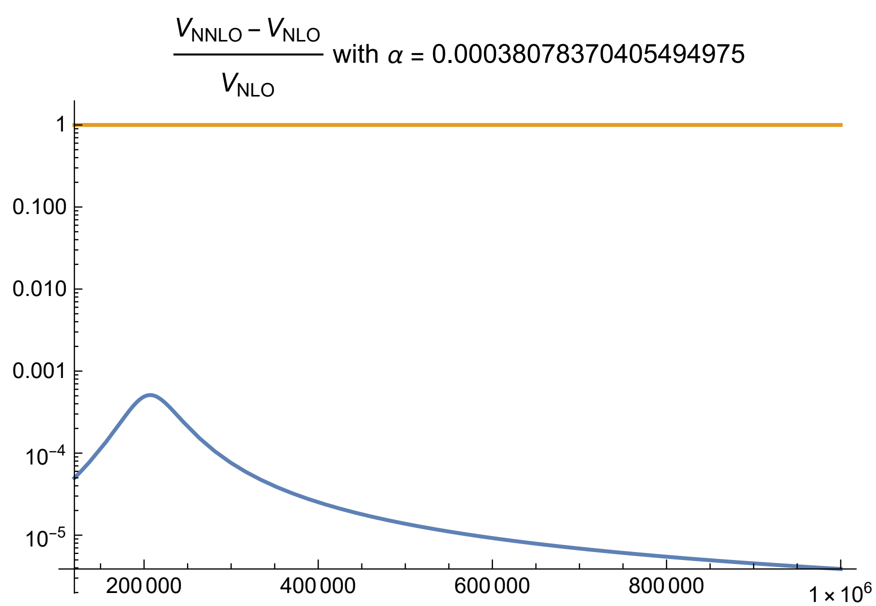


Green: dS solution. Blue: runaway.

Linear term part II



Linear term part II

Leading contribution comes from C at $\mathcal{O}\left(\frac{1}{\sqrt{\tau}}\right)$. The most important at large τ.

$$\frac{V_{LO}}{|W_0|^2} = \frac{\delta^2}{3s\tau^2} - \frac{2a\delta}{s^2\tau^2} + \frac{3\left(a^2+\alpha s^2\right)}{s^3\tau^4} = \frac{|W_0|^2}{3s\tau^2}\left(\delta - \frac{3a}{s\tau}\right)^2 + \frac{3|W_0|^2\alpha}{s\tau^4},$$

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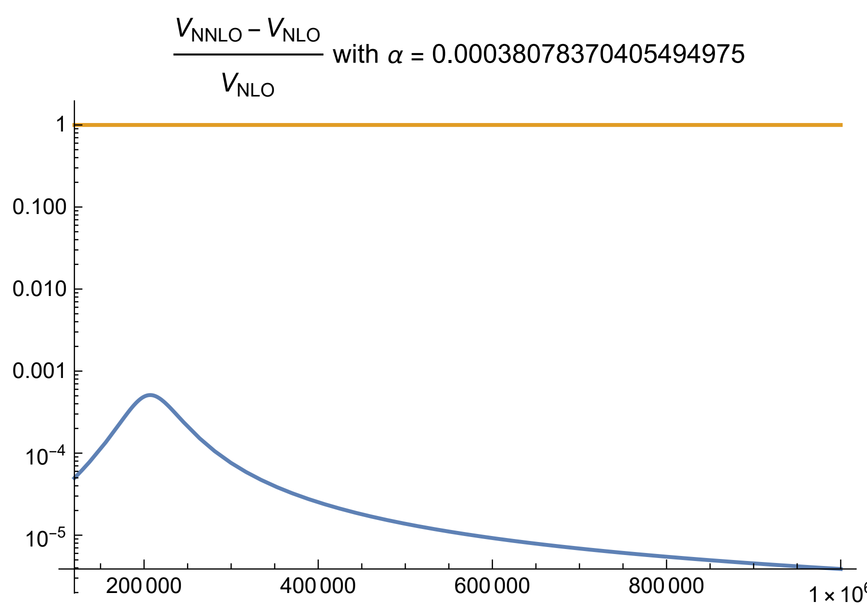

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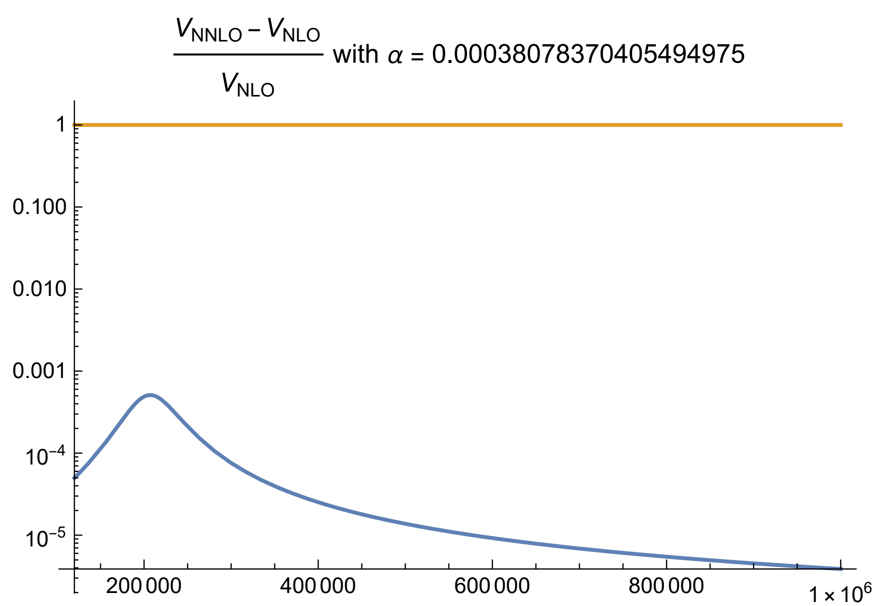

Figure.- Parameter space: $s=15$, $a=1$, $W_0=1$, $\delta=10^{-6}$, $\xi=0.1$, $A=1$. NNLO terms are suppressed.

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$$V_{LO} \sim \frac{\mathcal{O}(1)}{\tau^2 s} - \frac{\mathcal{O}(1)}{\tau^3 s^2} + \frac{\mathcal{O}(1)}{\tau^4 s^3} \sim s$$

and

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For increasing s we have some implications:

- The inverse dependence $\tau \sim s^{-1}$ implies that position of the minimum will move to smaller τ. Hierarchies between V_{LO} and V_{NLO} reduced by expansion in $\frac{1}{\tau}$.
- Coefficients in the NLO terms will increase more rapidly than the coefficients of the LO terms.
- NLO become dominant and therefore, for arbitrarily large s, the NLO corrections to the potential will become too strong leading to a runaway potential.
- To compensate for larger values of $s \rightarrow$ greater hierarchy between the LO and NLO terms $\rightarrow$ smaller $\delta \rightarrow$ larger τ at the minimum.
- Arbitrarily large $s \Rightarrow$ arbitrarily large τ $\rightarrow$cosmological moduli problem.

LINEAR TERM PART III

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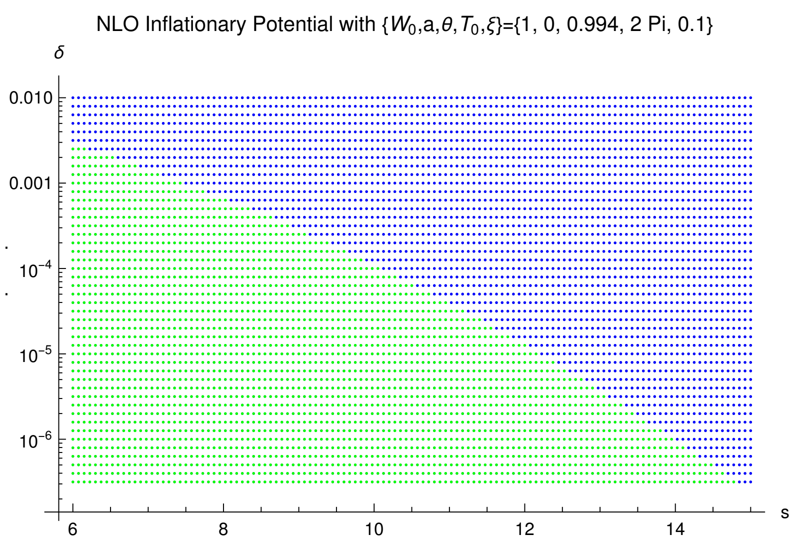
- To compensate for larger values of s → greater hierarchy between the LO and NLO terms → smaller δ → larger τ at the minimum.

- Arbitrarily large $s \Rightarrow$ arbitrarily large τ →cosmological moduli problem.

[K. J. Bae, H. Baer, V. Barger, and R. W. Deal, 2022]

Without linear term



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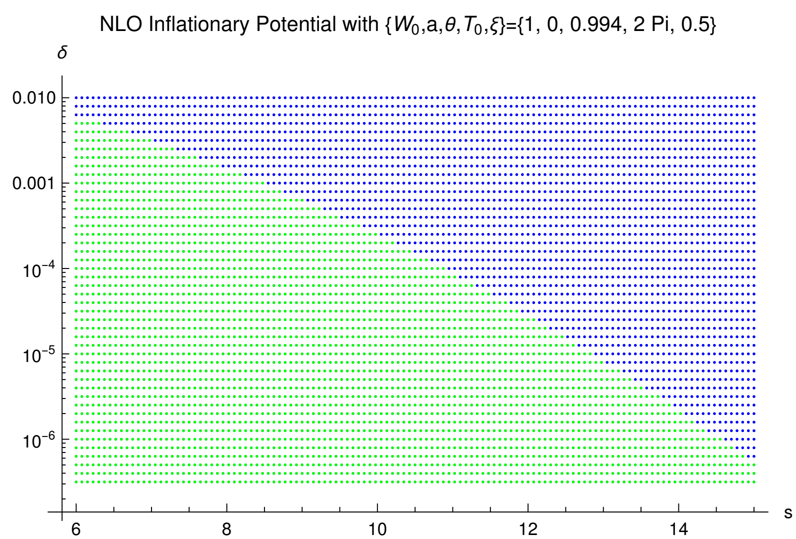


Without linear term

The Kähler potential is

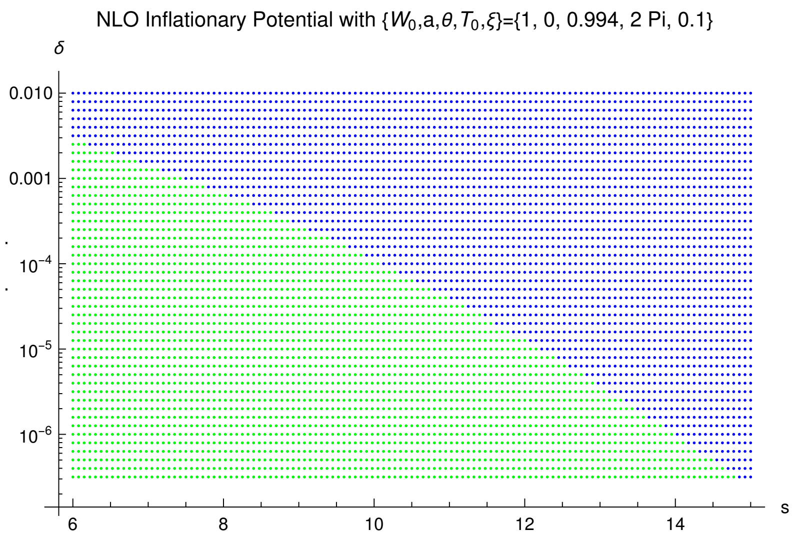
$$K = -\ln(s) - 3\ln\left[\tau - \alpha\ln(\tau) + \frac{s^2\xi - 3D\ln(\tau)}{3s^{1/2}\tau^{1/2}} - \frac{1}{2}X\bar{X}\right],$$

meanwhile the scalar potential becomes

$$\frac{V}{W_0^2} = \mathscr{A}\frac{\delta^2}{\tau^2} + \mathscr{C}\frac{1}{\tau^4} \quad , \quad \delta = \frac{|W_X|}{|W_0|},$$

where coefficients as in case with linear term but $a = 0$:

- $\mathscr{A} = \dfrac{1}{3s} - \dfrac{2As}{3s^3\tau} + \ldots,$
- $\mathscr{C} = \dfrac{3\left(\alpha s^2\right)}{s^3} + \dfrac{3\left(\xi s^2 + 8D + 3\sigma - 3D\ln(\tau)\right)}{4s^{3/2}\tau^{1/2}} + \dfrac{3s^2\left(3A^2 - 2\alpha As + 3\alpha^2 s^2\right)}{s^5\tau} + \ldots.$



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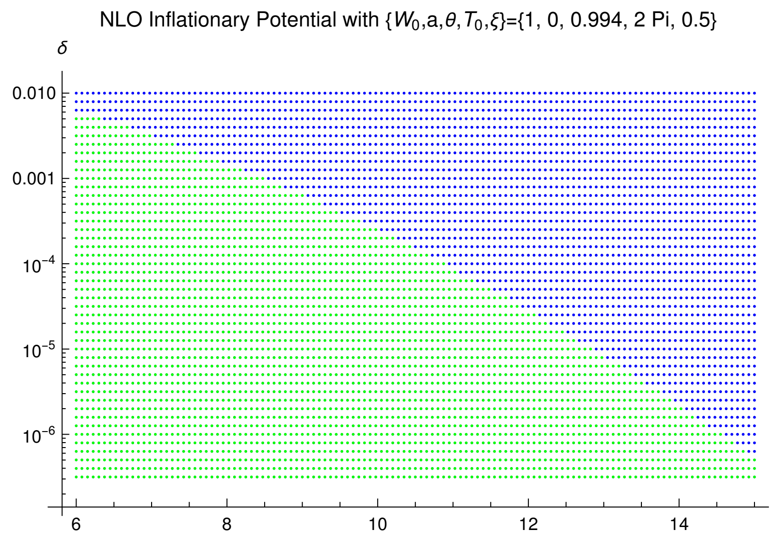

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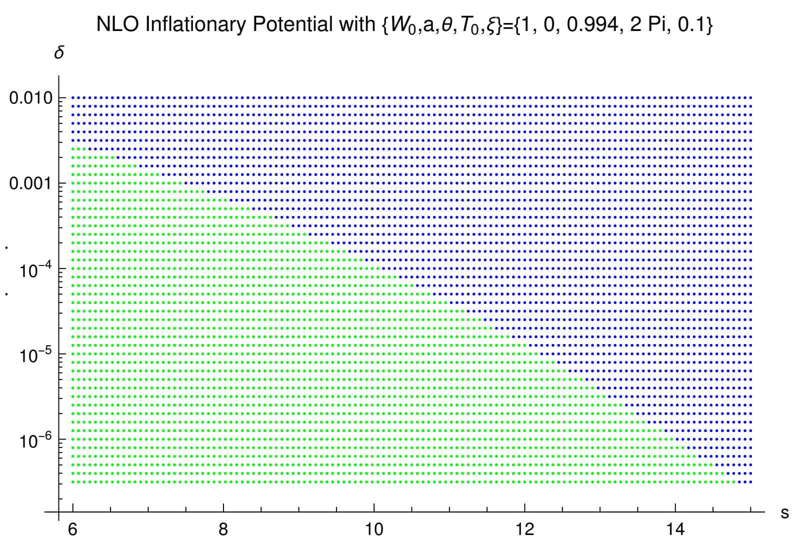

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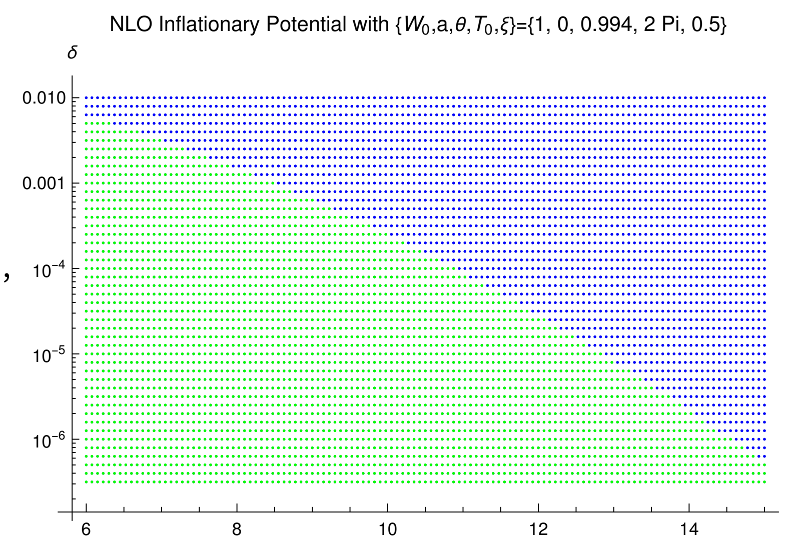
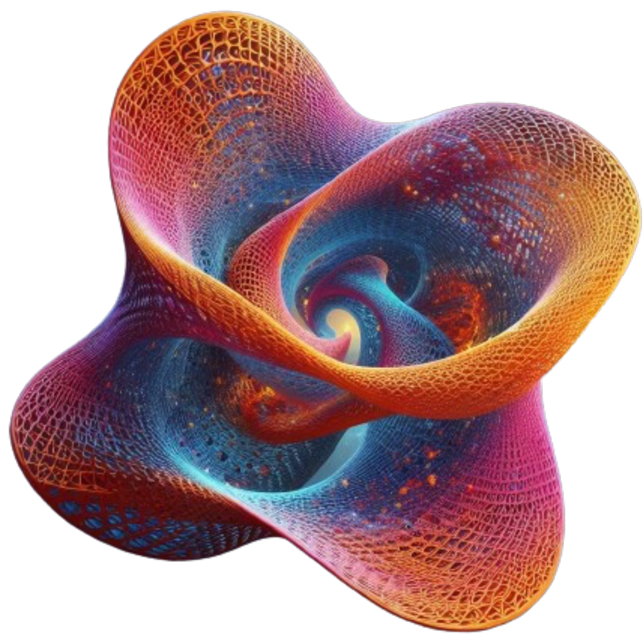


Green: dS solution. Blue: runaway.

Geometrical toolkit



Geometrical toolkit

Parameters for inflation, α and ξ, are constrained:

- ξ (and therefore D) is determined by the Euler characteristic χ.
- Kreuzer-Skarke CY database favours: $|\chi| < 200 \Rightarrow 0 < |\xi| < 5$.
- α is a one-loop beta function coefficient and is expected to be suppressed.